

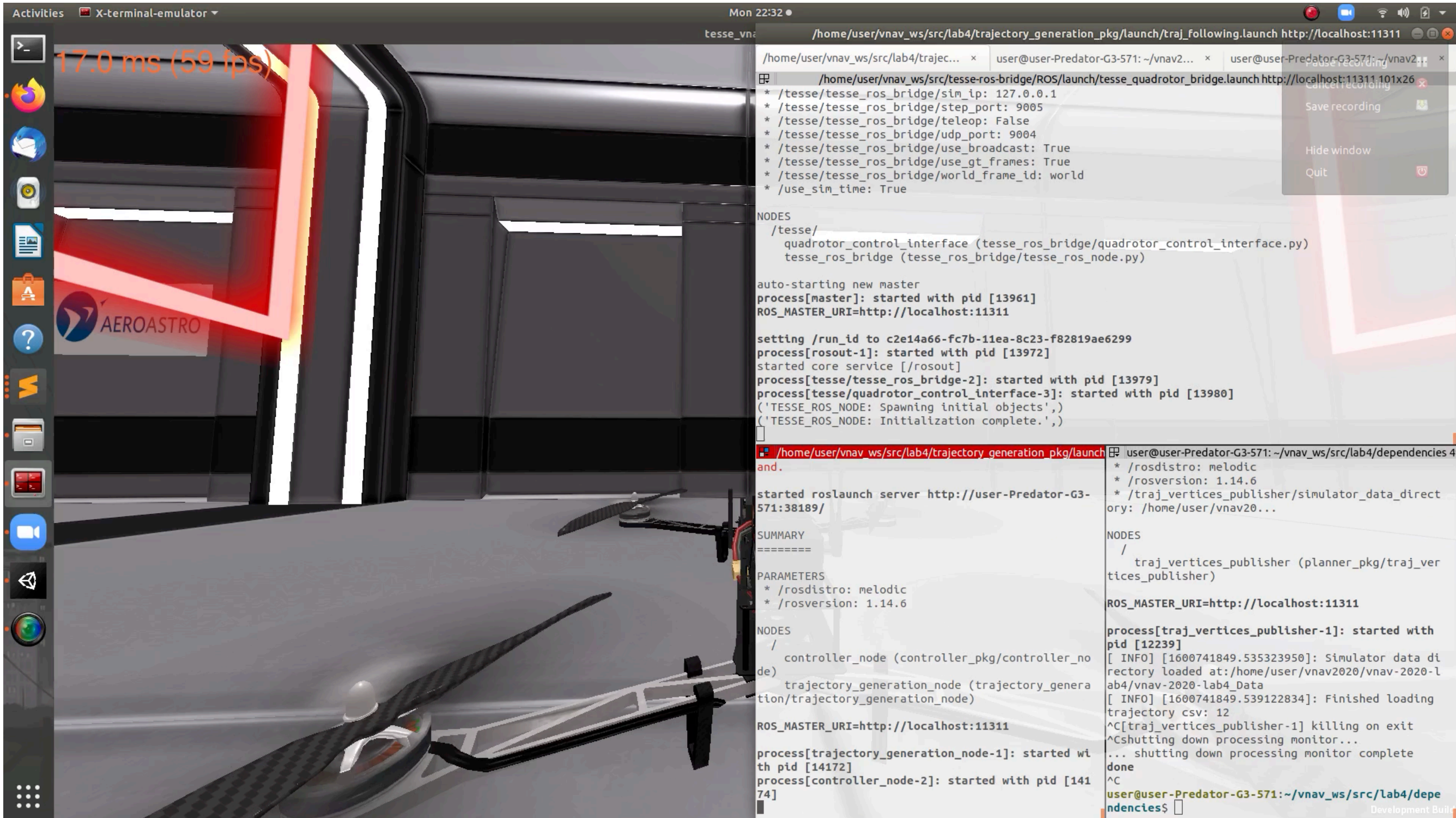


16.485: VNAV - Visual Navigation for Autonomous Vehicles
Lecture 11: Image Formation

Luca Carlone



What we learned so far

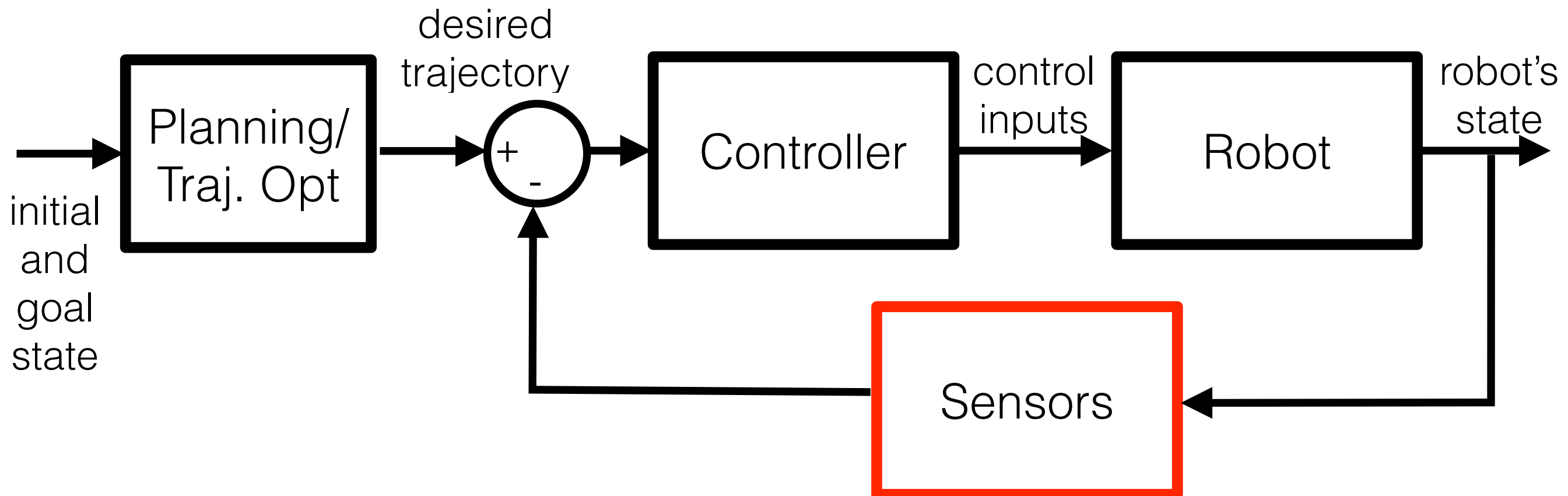


The screenshot displays a ROS simulation environment. On the left, a 3D view shows a drone in a simulated environment with a red and white structure. A performance overlay in the top left corner indicates a frame rate of 17.0 ms (59 fps). The right side of the image shows two terminal windows. The top terminal window displays the output of a ROS launch file, including parameters for the simulation and the list of nodes: `quadtrotor_control_interface` and `tesse_ros_bridge`. The bottom terminal window shows the output of another ROS launch file, including parameters for the simulation and the list of nodes: `controller_node` and `trajectory_generation_node`. The bottom terminal window also shows the output of a `traj_vertices_publisher` node, including the path to the simulator data directory and the trajectory CSV file.

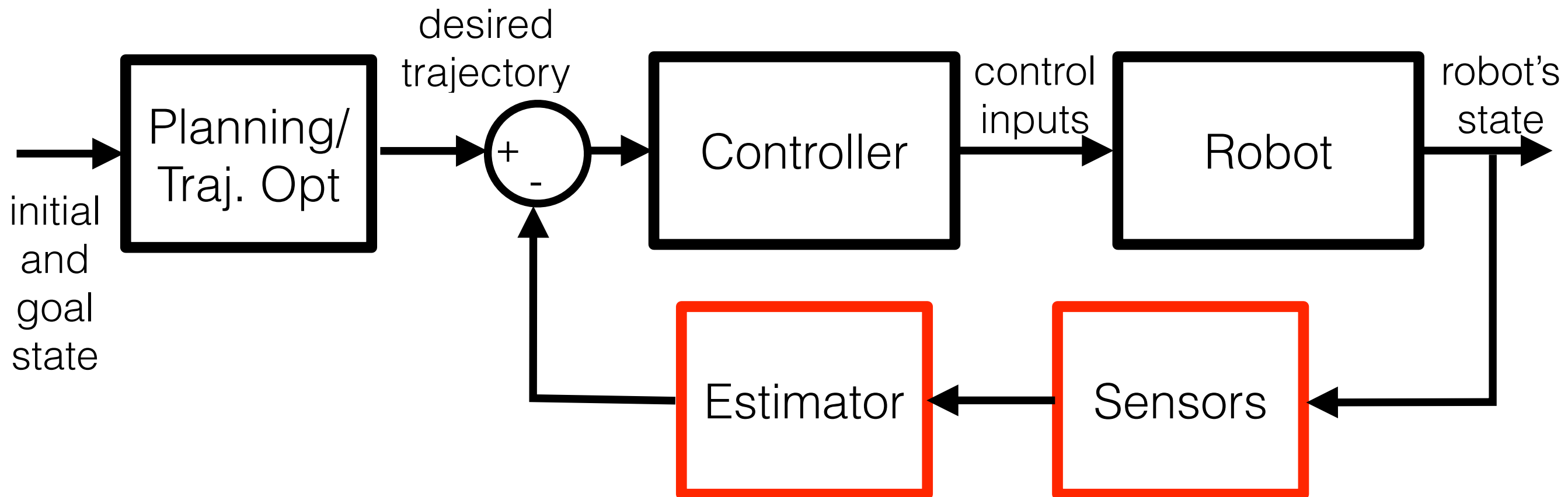
Requires:

- state of the drone (localization)
- obstacles (mapping)

What's next

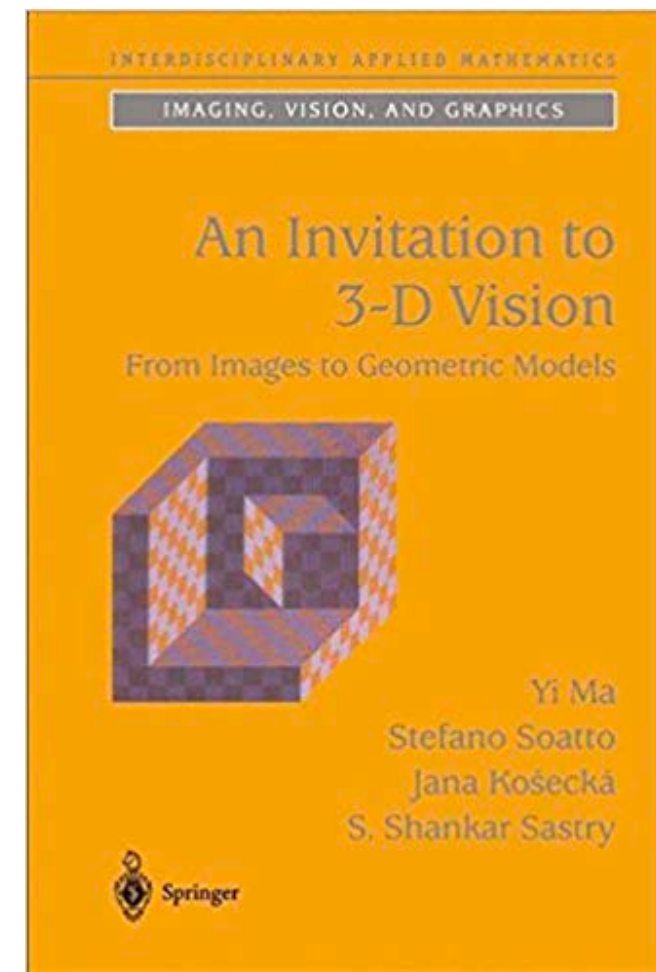


What's next



Today

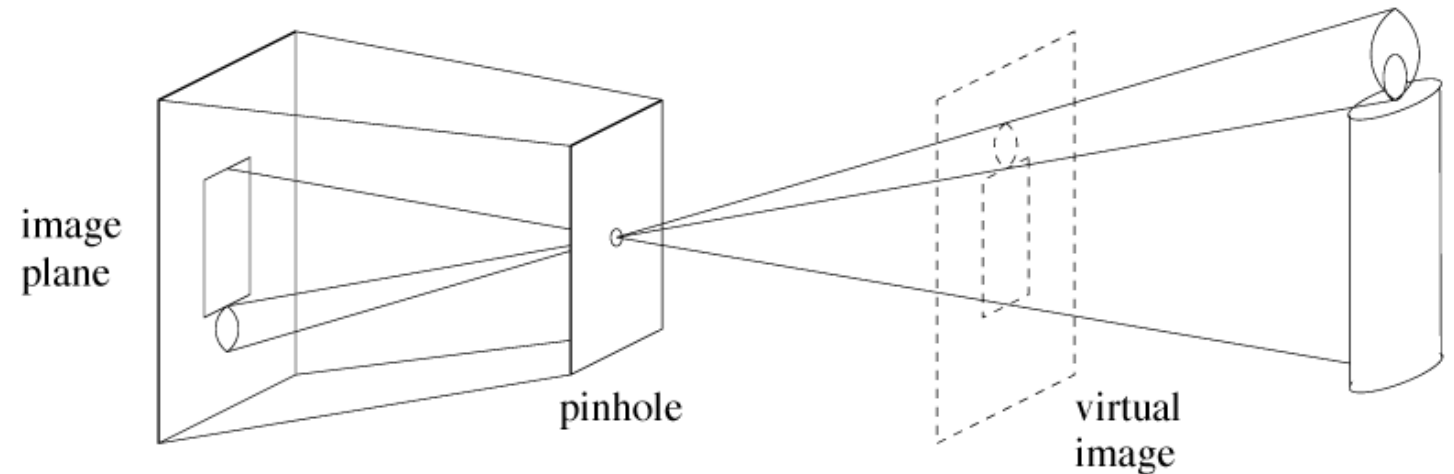
- Image Formation
- Pinhole Camera Model



Chapter 3 Image Formation

Image Formation

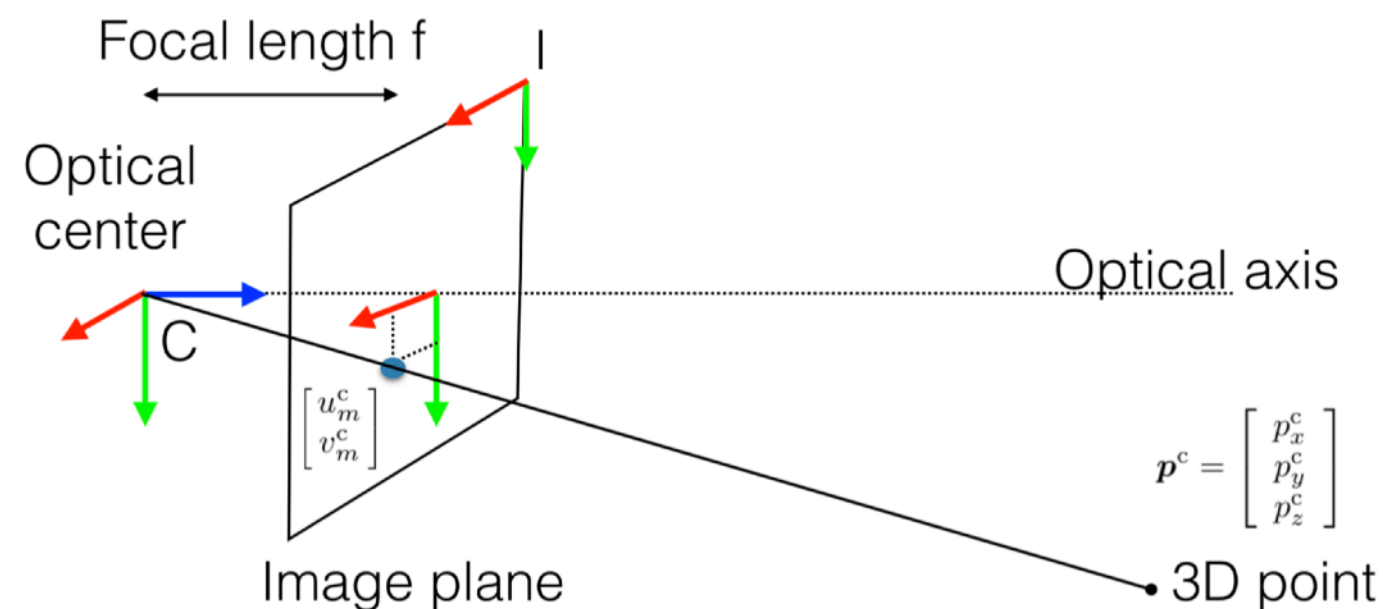
- How to capture a 3D scene on a 2D image?
- **Camera obscura**
(Latin: “dark room”):
 - optical device that projects 3D scene to a surface
 - box with a hole on one side
 - known for several centuries:
 - Mo Ti, Chinese philosopher (5th Century B.C.)
 - Leonardo da Vinci (1452-1519)



Frisius (1544)

Geometry: Pinhole Camera Model

- How to compute the 2D projection (pixel) of a given 3D point?



$$\mathbf{p}^c = \begin{bmatrix} p_x^c \\ p_y^c \\ p_z^c \end{bmatrix}$$

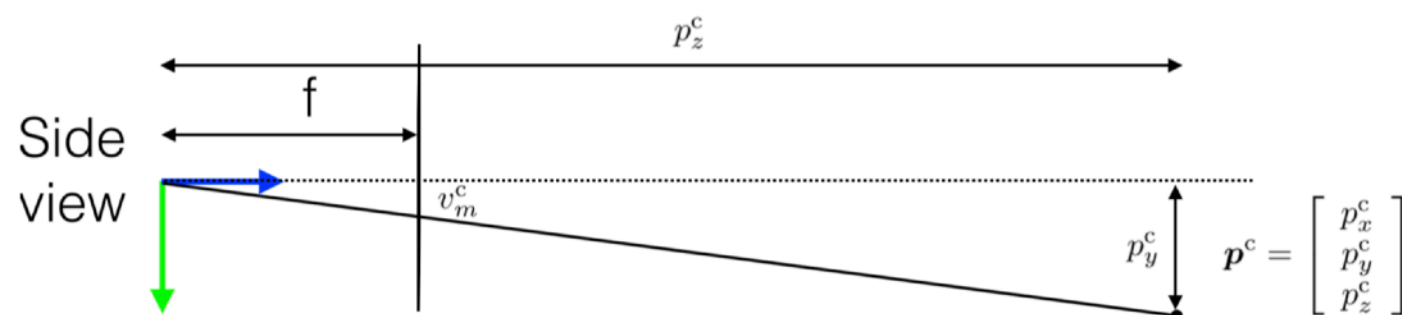
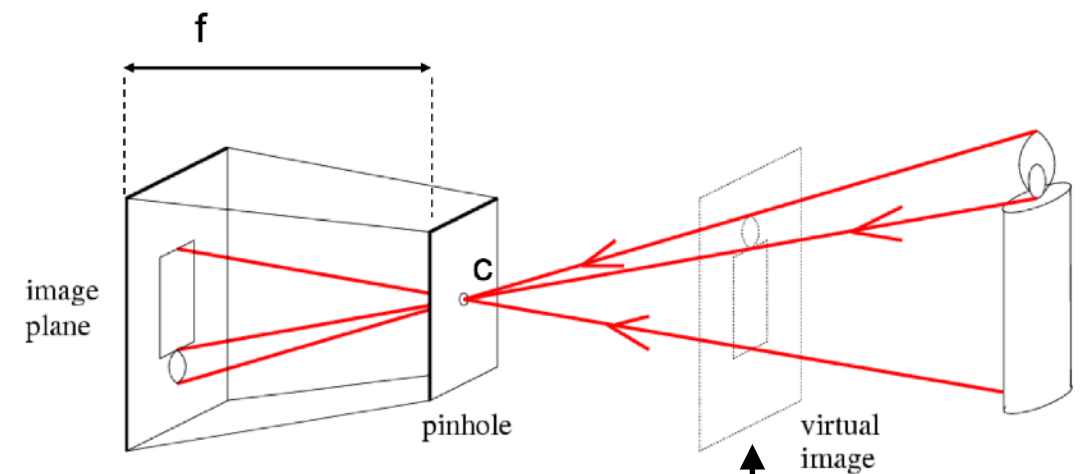


Figure 11.1: Pinhole Model.

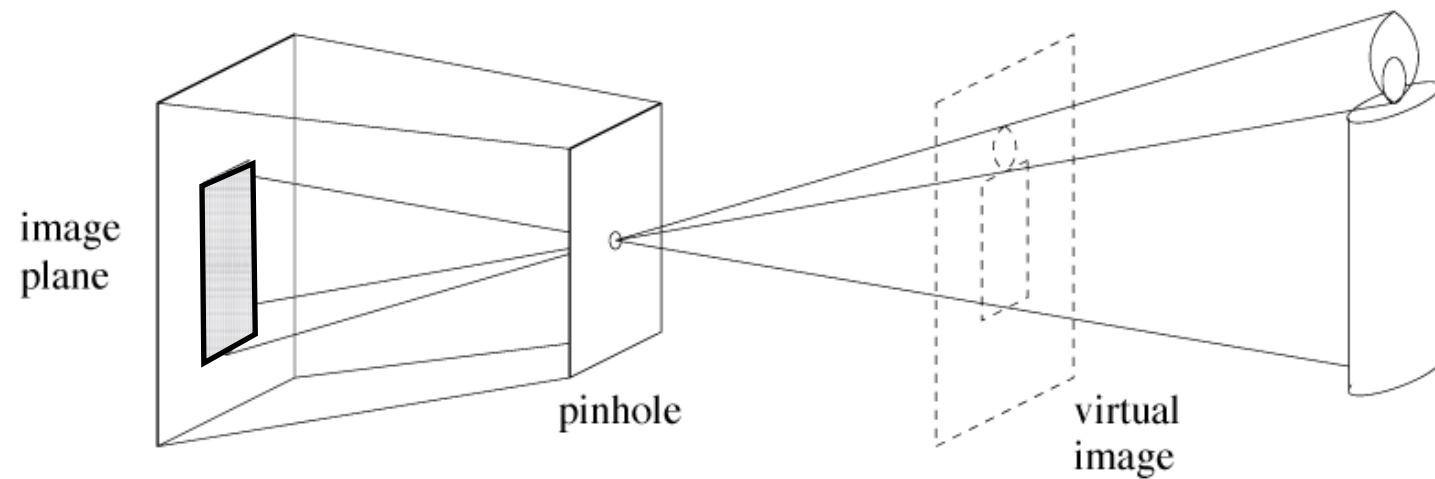


f = focal length
 c = center of the camera

Frontal
pinhole
model

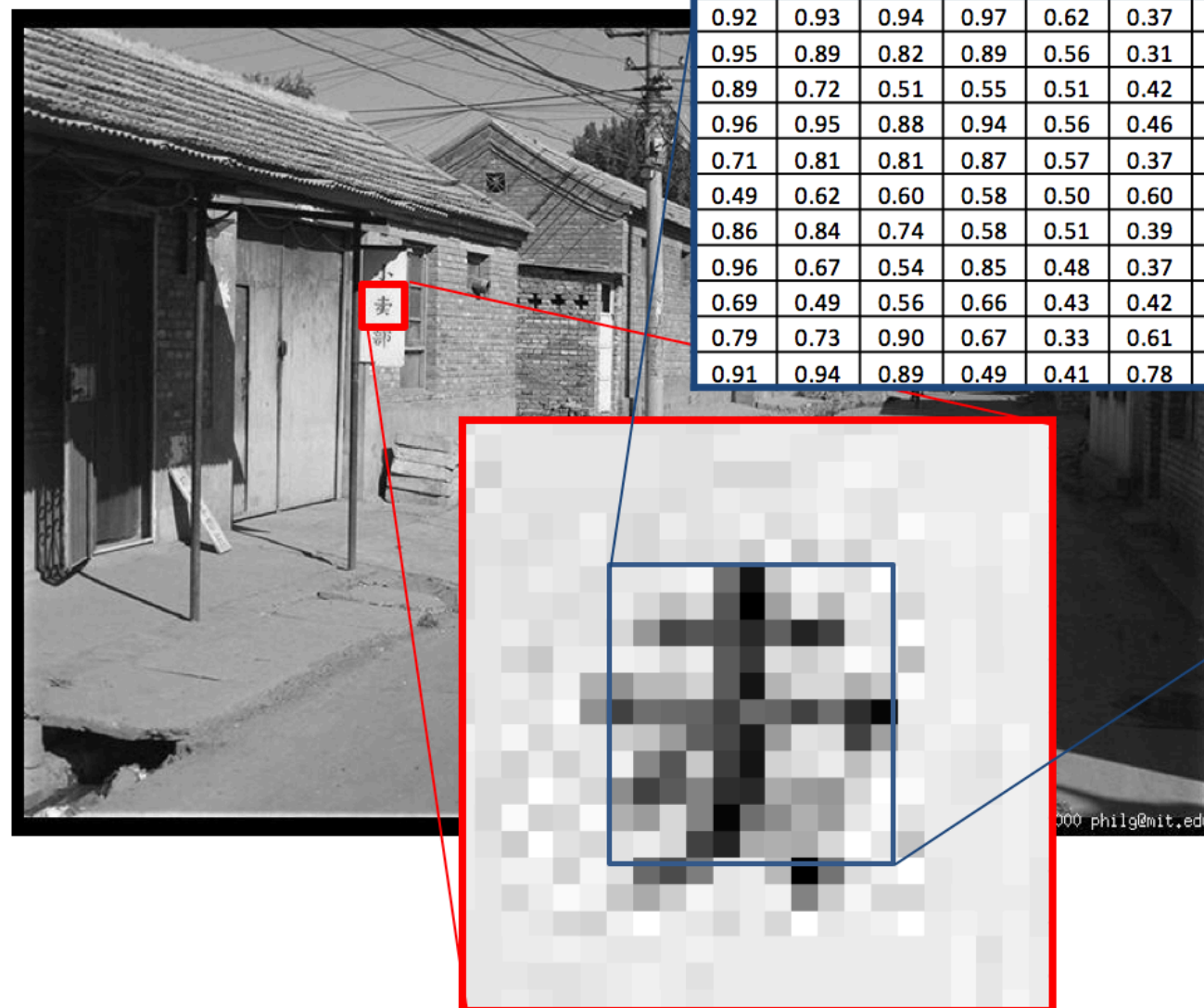
Let's do
some math

Digital Photography



2D array of
“light sensors”

- CCD (charge-coupled device, 1960)
- CMOS (complementary metal-oxide semiconductor, 1963)



0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

Appearance: Light and Colors



R
(G=0,B=0)

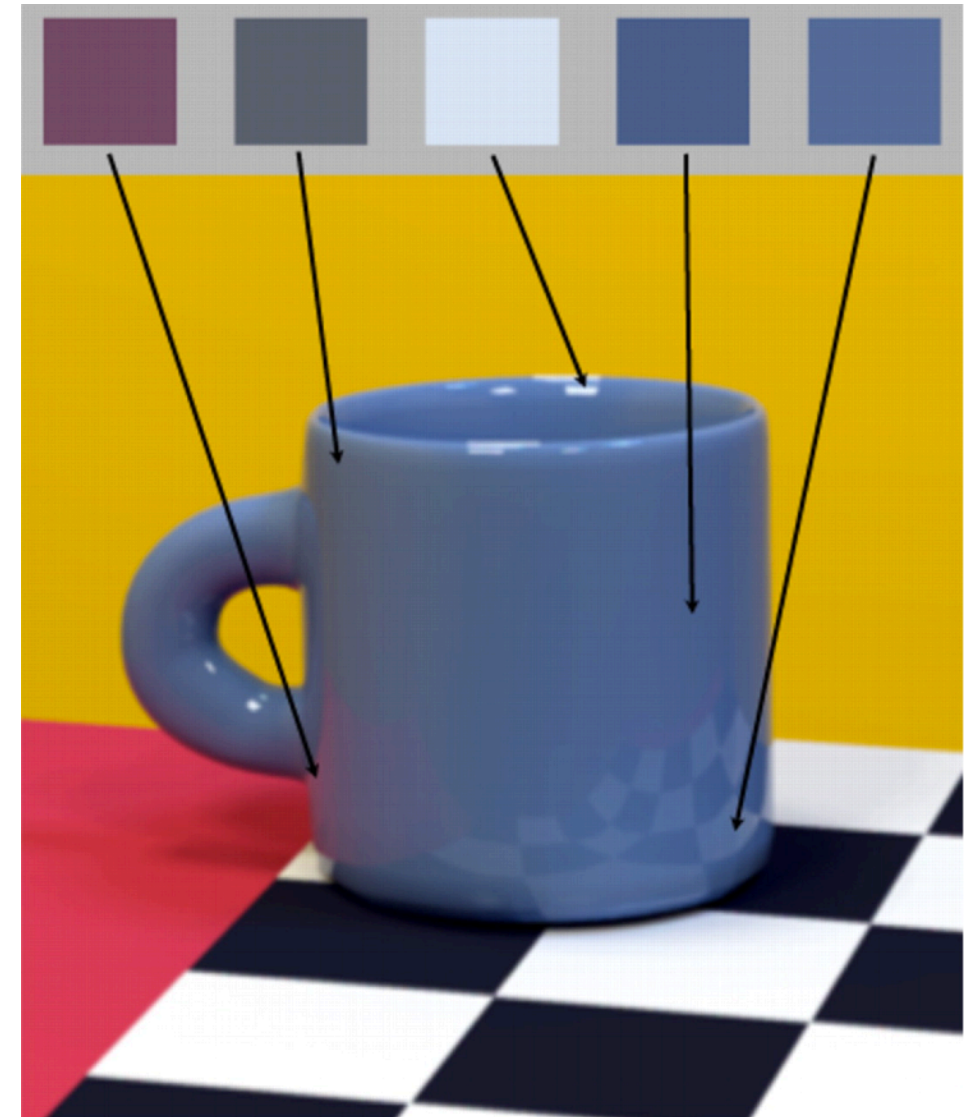
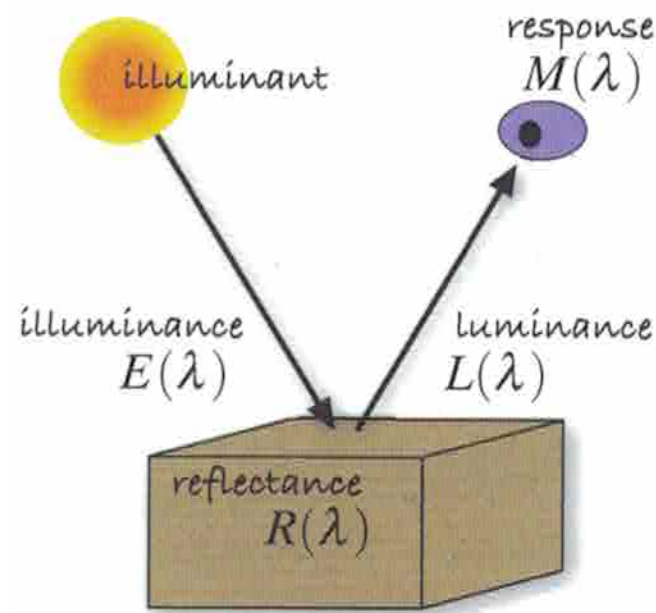


G
(R=0,B=0)



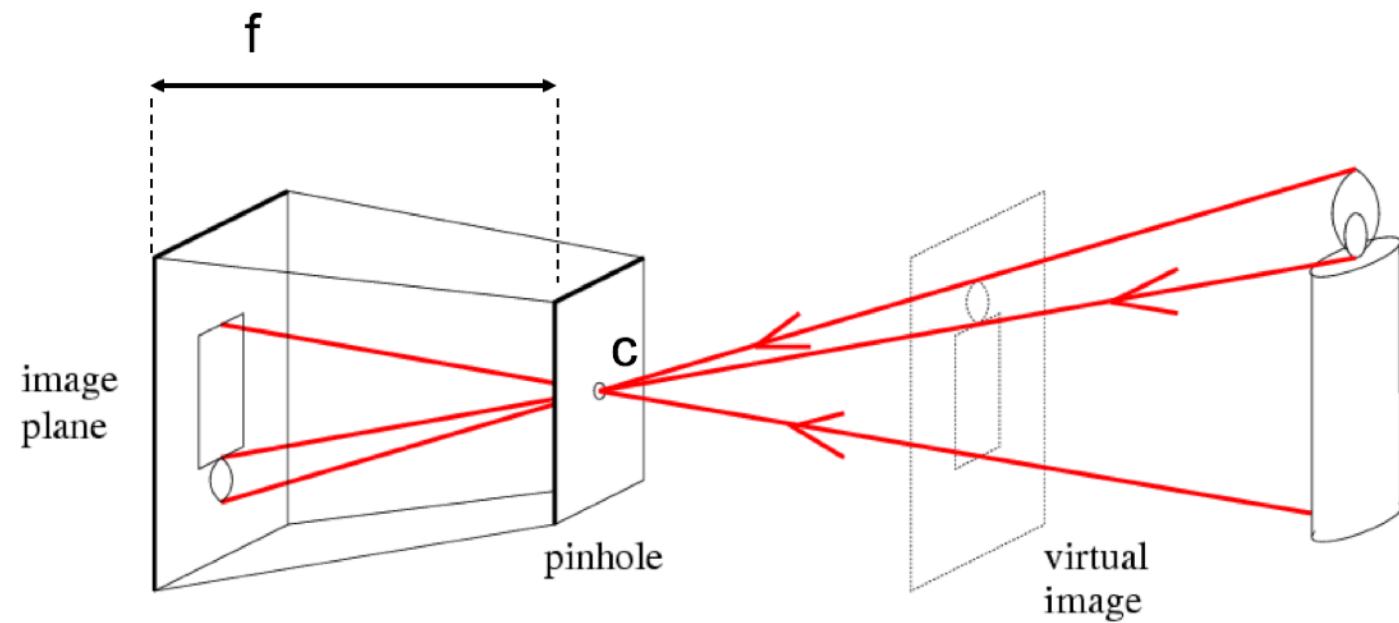
B
(R=0,G=0)

Perceived appearance is the result of (i) geometry, (ii) illumination, (iii) material properties

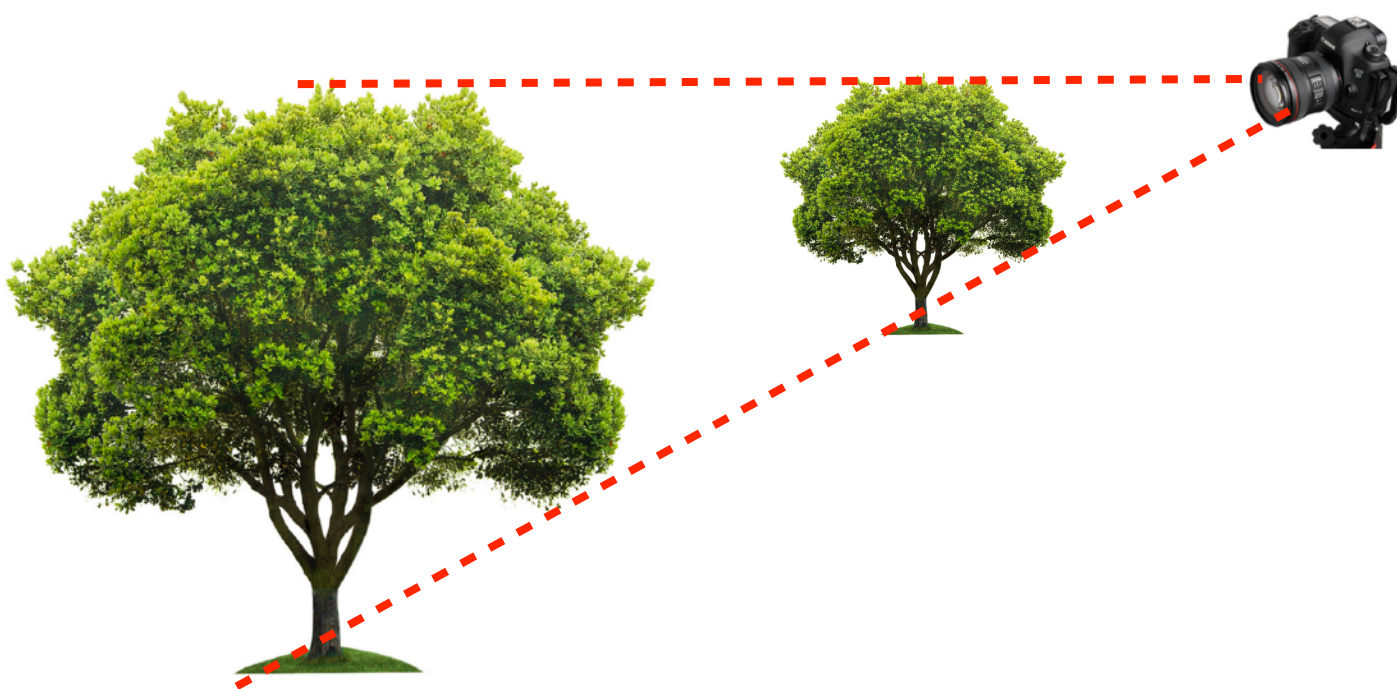


Perspective Projection

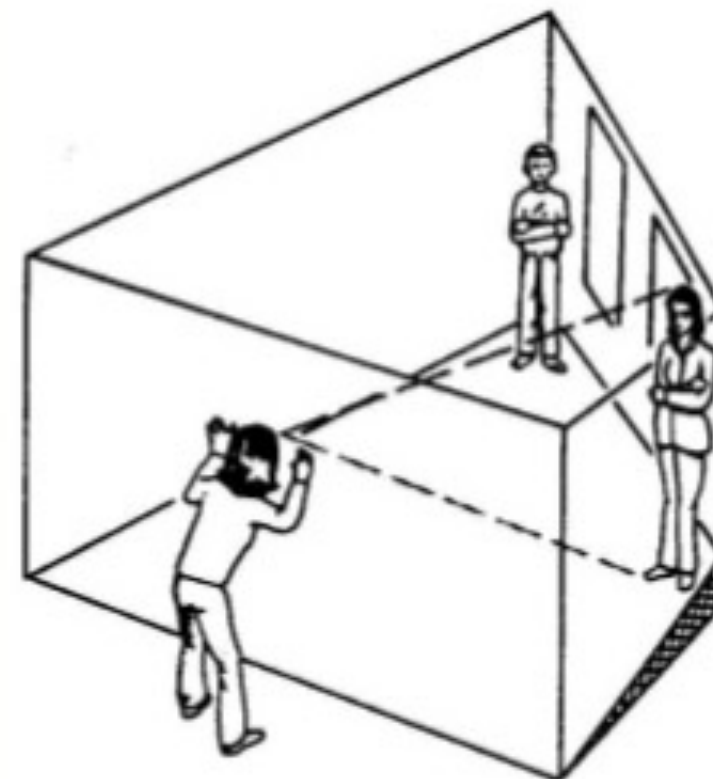
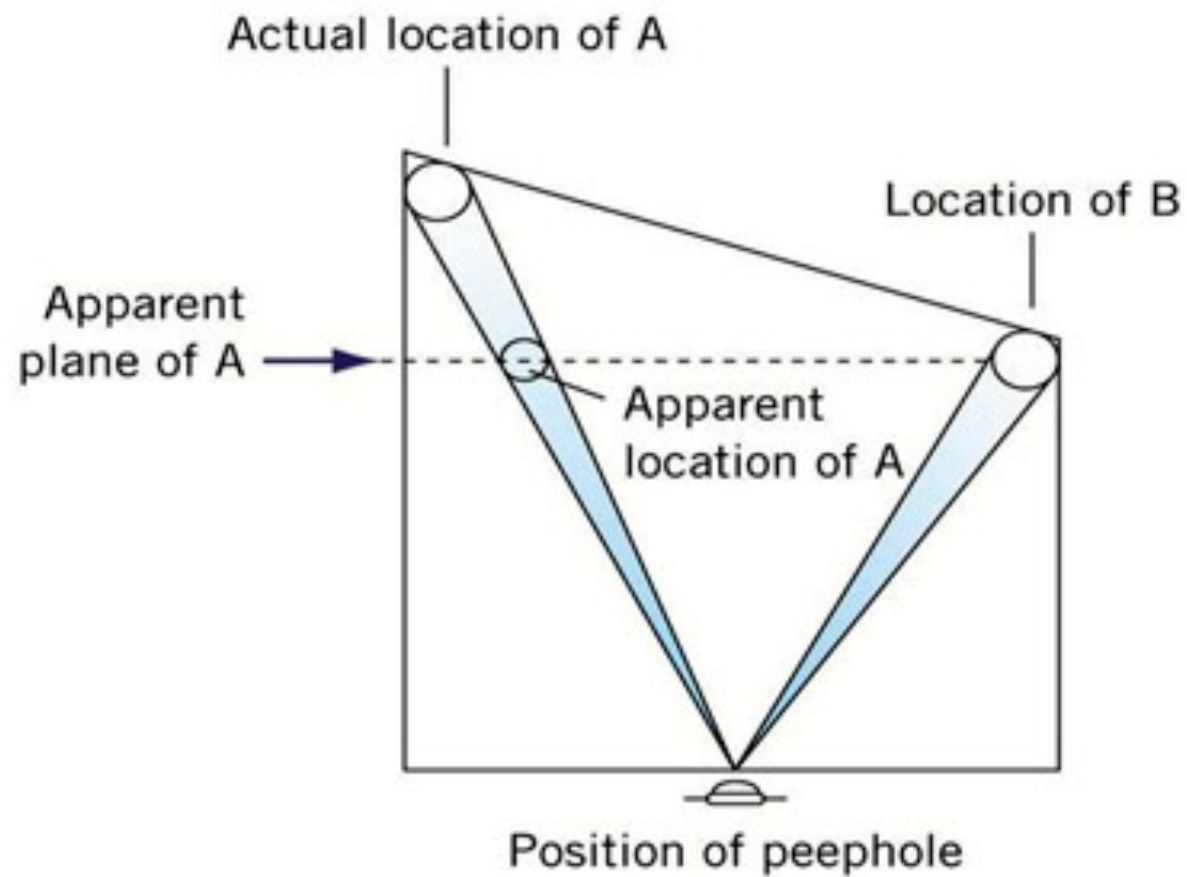
- what is lost?
 - depth?



f = focal length
 c = center of the camera



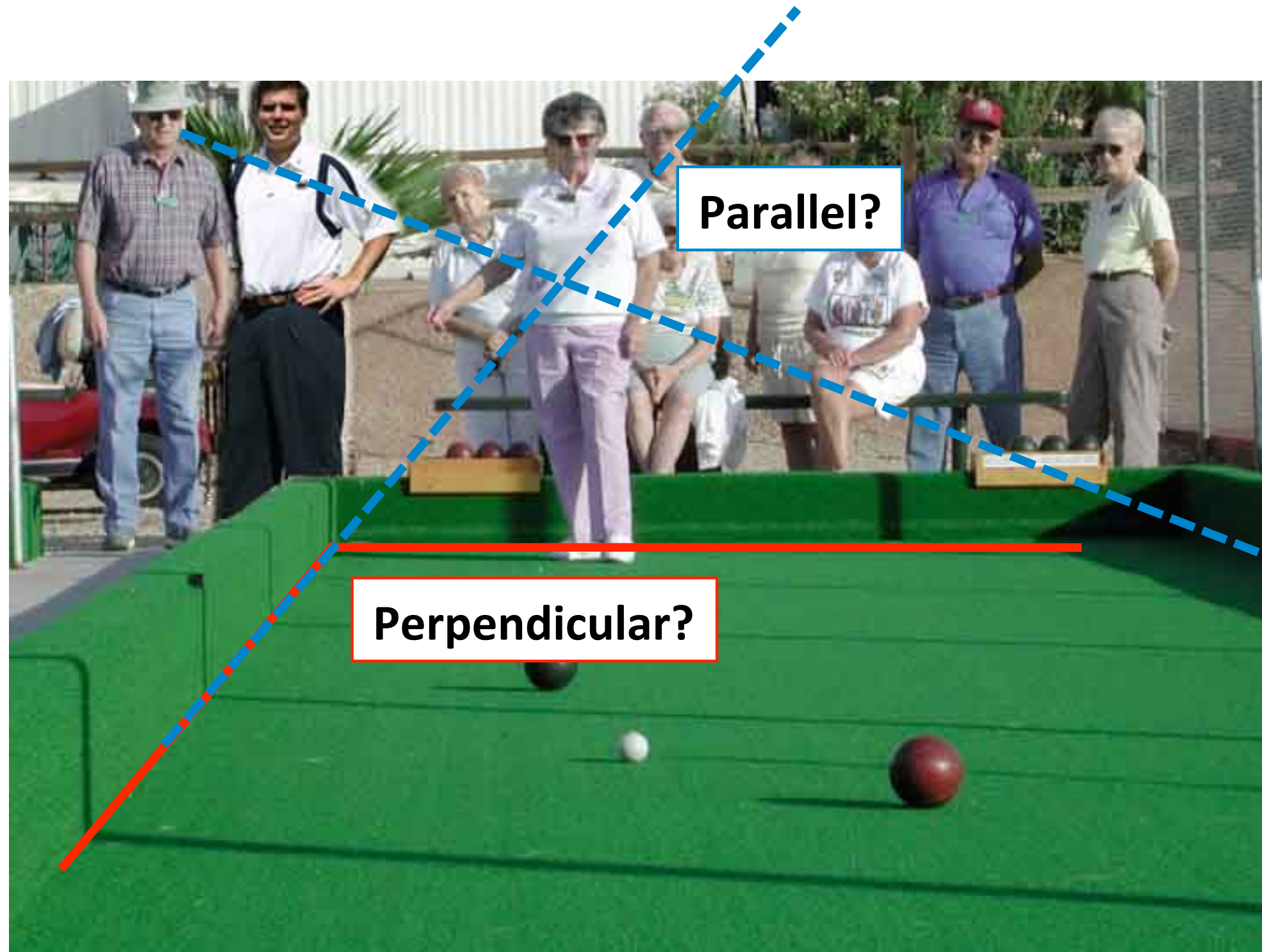
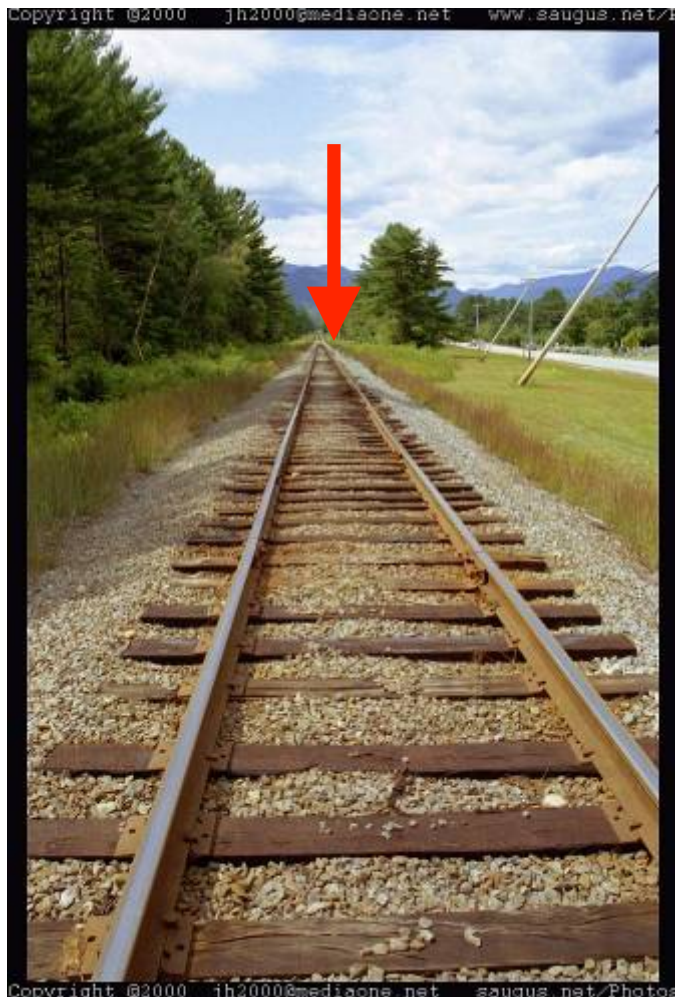
Ames Room



Ames, 1946

Perspective Projection

- what is lost?
 - depth?
 - length?
 - angles?



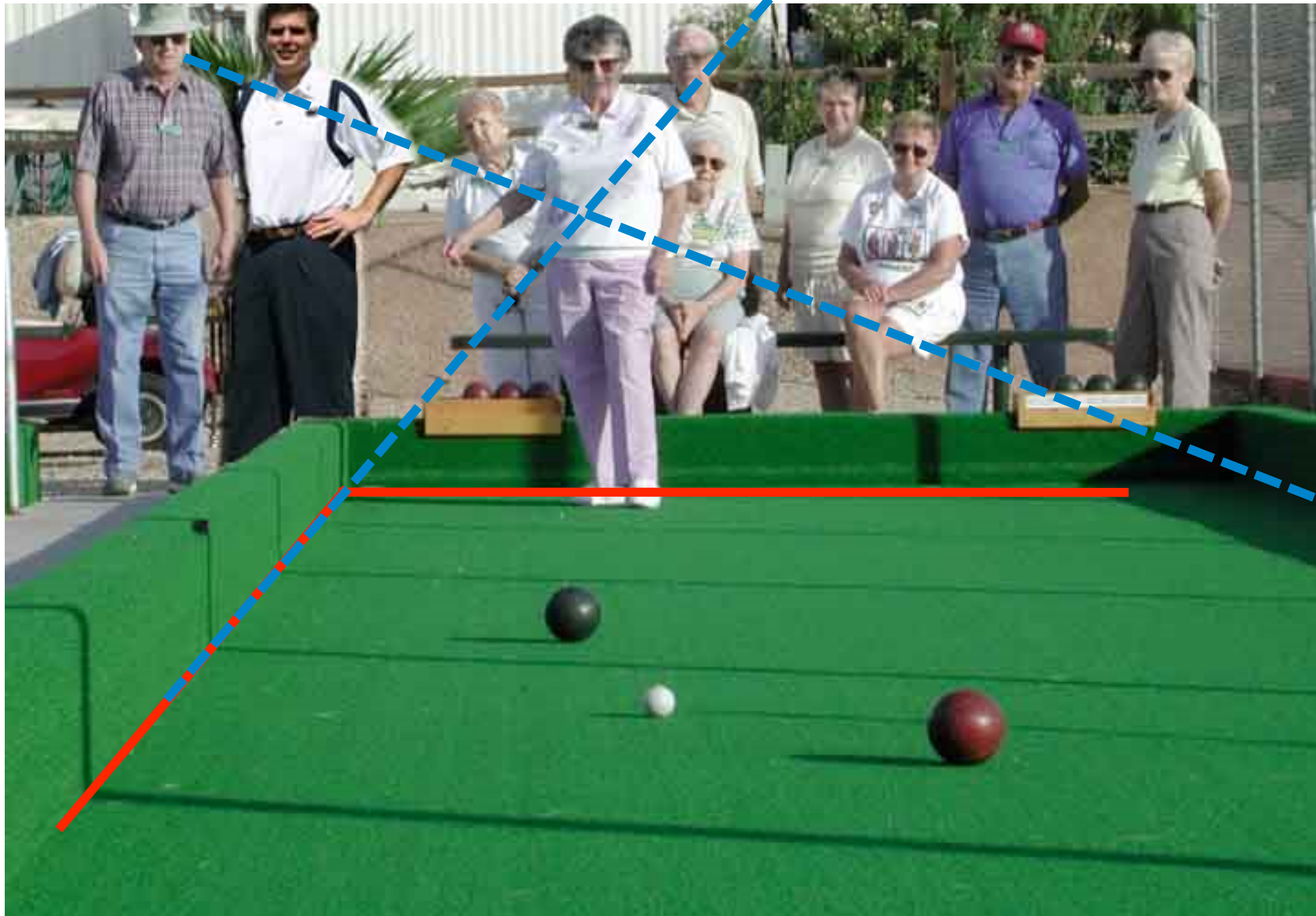
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Parallel lines which intersect ...

Slide adapted from
Frank Dellaert

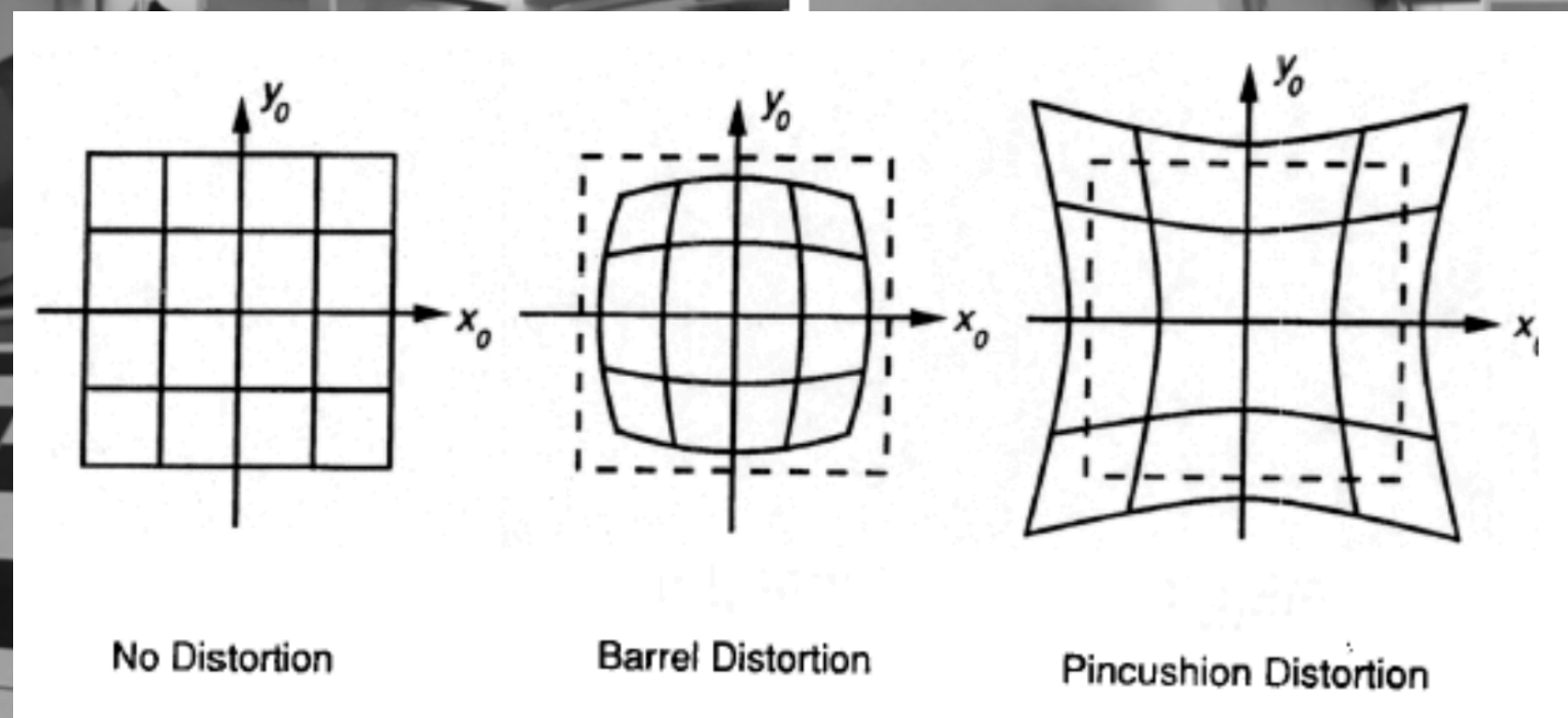
Perspective Projection

- what is preserved?
 - straight lines remain straight



The final Touch: Adding a Lens

- Pinhole model is based on the geometry of the **camera obscura**
- In practice: add a **lens** in front of the aperture to capture more light
- Pinhole model holds, but **distortion** may appear due lens imperfections



- distortion can be described mathematically using **distortion parameters**
 - can be estimated during calibration and compensated for (**undistortion**)